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Original article



Polyethylene Resistance to Oil and Associated Water

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Abstract

Introduction. Polyethylene is the most widely used material in various fields of the national economy, and products made of it have essential advantages, such as lightness, insolubility in organic solutions with quite satisfactory strength. However, the mechanism of its destruction is quite complex and depends on the working conditions and substances, which are in contact with it. The research purpose was to study the polyethylene resistance to oil and associated water under the static and dynamic conditions and at room temperature.

Methods and Materials. The research was carried out on a laboratory device for passing various liquids (oil, associated and distilled water) in polyethylene pipes, assembled by the author of the article. While working, methods of statistical and dynamic data processing were applied.

Results. Based on the results of previous experiments, graphs were plotted for the change in the weight and volume of immersed granules over time. They have shown that polyethylene has a quadratic dependence, and diffusion for the three liquids studied in this work (distilled water, accompanying water and oil) is described by Fick's law. This indicates the fact that the rate of liquid diffusion through polyethylene is the key factor.

Discussion and Conclusions. The obtained results have shown that the rate of liquid diffusion through polyethylene is the key factor. Immersion in oil has a greater impact than immersion in associated or distilled water due to the presence of salts. It has been found out that the relative change in the weight and thickness of the polyethylene pipe walls through which oil passes is greater than those through which the associated water passes. Moreover, the microscopic cross sections images in the samples before and after the tests have confirmed the obtained results.

Keywords: Polyethylene, associated water, solid materials, salts, distilled water.

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Научная статья

Устойчивость полиэтилена к нефти и сопутствующей воде

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Аннотация

Введение. Полиэтилен является наиболее широко применяемым материалом в различных областях народного хозяйства, а изделия из него обладают существенными достоинствами, такими как лёгкость, нерастворимость в органических растворах при вполне удовлетворительной прочности. Однако механизм его разрушения достаточно сложен и зависит от условий работы и контактирующих с ним веществ. Цель исследований

заключалась в изучении устойчивости полиэтилена к нефти и сопутствующей воде при статическом и динамическом режиме и комнатной температуре.

Материалы и методы. Исследования проводились на лабораторном устройстве для пропускания различных жидкостей (нефть, сопутствующая и дистиллированная вода) в полиэтиленовых трубах, собранном авторами статьи. При работе были применены методы статистической и динамической обработки данных.

Результаты исследования. Графики изменения веса и объема погруженных гранул во времени, построенные по результатам проведенных экспериментов, показали, что для полиэтилена характерна квадратичная зависимость и диффузия для трех исследуемых в данной работе жидкостей (дистиллированная вода, сопутствующая вода и нефть) описывается законом Фика. Это указывает на тот факт, что скорость диффузии жидкости через полиэтилен является наиболее важным фактором.

Обсуждение и заключения. Эксперименты и полученные результаты показали, что скорость диффузии жидкости через полиэтилен является наиболее важным фактором. Погружение в нефть оказывает большее влияние, чем погружение в сопутствующую или дистиллированную воду из-за присутствия солей. Было обнаружено, что относительное изменение веса и толщины стенок полиэтиленовых труб, по которым проходит нефть, больше тех, по которым проходит сопутствующая вода, а микроскопические изображения срезов в образцах до и после испытаний подтвердили полученные результаты.

Ключевые слова: полиэтилен, сопутствующая вода, твердые материалы, соли, дистиллированная вода.

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Для цитирования. Антибас И.Р. Использование метода конечных элементов для моделирования резервуара высокого давления из полимера, армированного углеродным волокном. *Advanced Engineering Research (Rostov-on-Don)*. 2023;23(1):55–65. <https://doi.org/10.23947/2687-1653-2023-23-1-55-65>

Introduction. Polyethylene is one of the main elements of the olefin family, which is usually characterized by a waxy appearance, chemical inertia and physical properties deterioration at high temperatures. Since polyethylene is a partially crystallized material and does not go into secondary chemical reactions with any liquids, it has no solvents, and its water absorption at ambient temperature is relatively low.

Polyethylene does not dissolve in organic solutions, but it expands at a temperature of more than 70 °C and dissolves in granular aromatic hydrocarbons, it is not affected by oil, fats, kerosene and other hydrocarbons. It is also resistant to aqueous solutions of acids, salts and alkalis [1–5].

Polyethylene is oxidized by nitric acid, which causes a deterioration in the characteristics of the products obtained from it. Oxidation occurs in the presence of ultraviolet rays at ambient temperature, causing final brittleness and deterioration of the mechanical and thermal insulation properties [6–8]. The scientific interest is focused at the practical interaction study of polyethylene and oil, which is a mixture of hydrocarbon materials consisting mainly of compounds containing carbon and hydrogen as well as some elements mixed with hydrocarbons, such as sulfur, nitrogen and oxygen, in addition to metal elements in simple proportions, such as iron, nickel, arsenic and vanadium. Along with them, chlorides salts of land-based minerals as well as their sulfates are present in oil. Moreover, oil contains water in certain percentages, depending on its type and production conditions, and this percentage can increase up to 30 % relative to the total volume of oil, since it is in the form of saturated solutions of sodium chloride, magnesium sulfate and calcium. Carbon dioxide and hydrogen sulfide gases dissolving in water increase its volume. Acid and oxygen, reacting with iron and manganese dissolved in the associated water, form insoluble products. The associated water contains a small percentage of organic chloride salts, not exceeding 50 parts per million [9, 10].

The impurities contained in crude oil (solid materials – salts – water – chemical additives) cause serious risks to the oil refining equipment, its operating time and efficiency. Polymer materials are known to be destroyed in a completely different way than metal materials; therefore, when producing various products from them, it is necessary to take into account their physico-chemical properties and electrochemical reactions.

Plastics cannot dissolve like metals, but they are damaged or destroyed due to swelling, that is, the so-called embrittlement occurs, in which they soften, harden and change colour, which leads to their mechanical properties deterioration.

There are several mechanisms of polymer materials destruction:

– structure swelling;

– dissolution;

– bonds are destroyed under heat, chemical reactions or free radical reactions. The surface layer embrittlement can occur by any one mechanism or by a combination of mechanisms [11–13].

Dissolution and swelling without breaking chemical bonds are the main causes of embrittlement upon contact with impurities, and this process is complex, since small amounts of polymer solution penetrate inside [14], forming a seeping layer with altered physical properties (Fig. 1).

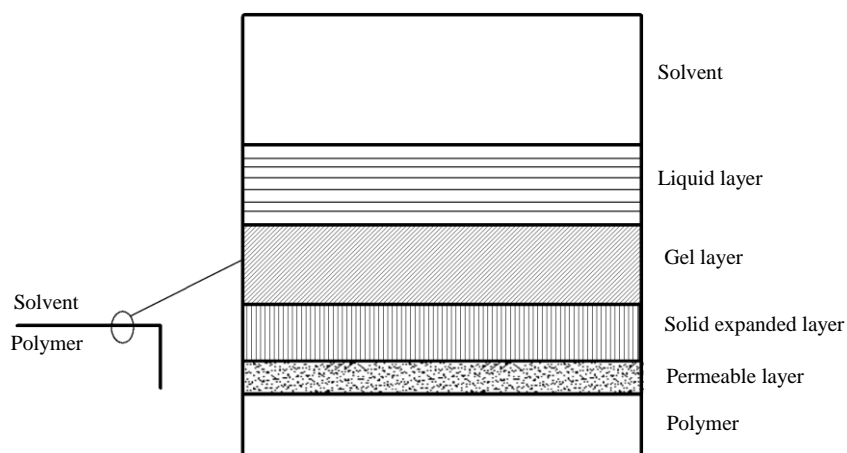


Fig. 1. Layer-structure of embrittlement process

The research objective is to study the polyethylene resistance to oil and associated water at room temperature, both at rest and in motion.

Materials and research methods. Table 1 shows the substances dissolved in oil after its extraction.

Table 1

Substances soluble and insoluble in oil after its extraction

Soluble substances			Insoluble substances	
solid substances		gases	metal substances	organic substances
positive electrolytes: $Mg^{+}, Fe^{+}, K^{+}, Na^{+}, Mn^{+}$ negative electrolytes: $Br^{-}, Cl^{-}, F^{-}, CO_3^{-2},$ SO_4^{-2}, HCO_3^{-}	plants and animals	$O_2, H_2S,$ N_2, CO_2	$Fe(OH)_3,$ $FeS_2,$ SCO_2 sand with clay substance, sulfate compounds, carbonates, alkaline land- based minerals.	Compounds obtained as a result of the addition of demulsifiers, bacteria, aquatic plants as well as plant and animal residues.

Table 2 shows the composition of the associated water used in the experiments.

Table 2

Composition of associated water used in experiments

Analysis	Measured value	Measurement units
Density	1.015	gr/cm ³
Cl^-	10,100	ppm
Na^+	2,427	
Mg^+	370	
Ca^{2+}	1,270	
Total stiffness $CaCO_3$	4,243	
Alkalinity $(CaCO_3)_m$	530	
SO_4^{-2}	1,093	
NO_3^-	100	
NH_4^-	13	
H_2S	130	
PH	8.5	

Petroleum alcohol was used as a cleaning agent. The experiments were carried out using granules and pipes made of high-pressure polyethylene HDPE of low density (Table 3).

Table 3

Technical characteristics of polyethylene granules and pipes used in the experiments

	Granules	Pipes
Type	Low-density high-pressure polyethylene	
Density	0.914	0.917
Shore hardness	44.6	46.7
Elongation-to-cut ratio	absent	4.42
The degree of softening onset	109-122	110-112

Laboratory instruments. Oil and associated water passed through polyethylene pipes in a laboratory device assembled by the author (Fig. 2). The complex of equipment included:

- sealed glass containers;
- scale with a sensitivity of ± 0.1 g, %;
- electronic micrometer with an accuracy of 1 micrometer;
- electronic microscope connected to a computer
- An electron microscope connected to a computer.

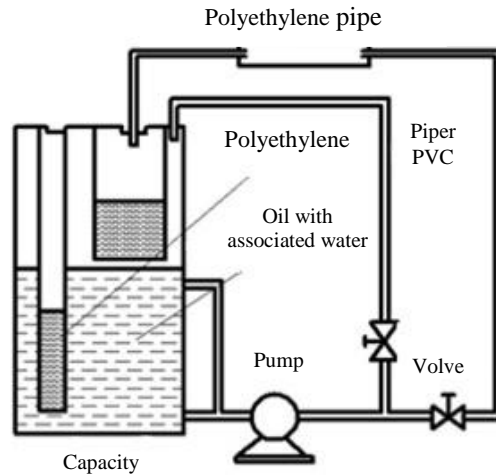


Fig. 2. Laboratory device for passing oil and associated water in polyethylene pipes

Experiments. In calm mode (immersion method), the sequence of actions when setting up the experiment was as follows:

- weight W_1 and volume V_1 were determined for several polyethylene granules samples, the characteristics of which are given in Table 3;
- the samples were completely immersed in oil, associated and distilled water in the sealed containers for certain periods of time;
- the taken samples were cleaned;
- the sample weight was determined as W_2 and its volume as V_2 during the experiment;
- the weight change was calculated as $\Delta W = W_2 - W_1$ and the volume change – as $\Delta V = V_2 - V_1$,
- the relative weight change as $\frac{\Delta W}{W_1} \cdot 100$ and the relative volume change as $\frac{\Delta V}{V_1} \cdot 100$ were calculated after each

sample testing.

In dynamic mode:

- oil and associated water flowed in the polyethylene pipes at a constant speed at the ambient temperature, their weight as W_1 and the wall thickness were determined for specific periods of time;
- the pipes were cleaned after each experiment;
- their weight as W_2 was determined after the experiment W_2 , and the wall thickness – after the experiment as X_2 ;
- the weight change was determined as $\Delta W = W_2 - W_1$, the volume change was as $\Delta V = V_2 - V_1$, the relative weight change was as $\frac{\Delta W}{W_1} \cdot 100$ and thickness change was as ΔX after the experiment.

Results and discussion

The weight and volume changes test results of particles immersed in oil, associated and distilled water were summarized in Tables (4–9). A graphical dependence was found for the relative weight and size changes of oil granules immersed in water, associated and distilled water (Fig. 3 and 4).

Table 4

Weight change of granules immersed in oil

No.	1			2			3		
	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %
10	27.022	27.673	2.240	26.9611	27.5542	2.200	25.384	25.921	2.261
30	26.652	28.6376	7.450	26.4489	28.4589	7.600	26.577	28.613	7.661
60	25.839	28.2497	9.330	23.486	25.7346	9.574	25.266	25.266	9.396
90	26.863	29.6979	10.55	27.3432	30.1732	10.350	25.683	25.683	10.28

Table 5

Volume change of oil granules

No.	1			2			3		
	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %
10	50.0	51.0	2.0	50.0	51.0	2.0	50.0	51.0	2.0
30	50.0	52.1	4.2	50.0	52.4	4.8	50.0	52.3	4.6
60	50.0	53.0	6.0	50.0	53.0	6.0	50.0	53.0	6.0
90	50.0	53.7	7.4	50.0	53.7	7.4	50.0	53.9	7.8

Table 6

Weight change of granules immersed in the associated water

No.	1			2			3		
	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %
10	55.045	55.430	0.70	58.765	58.765	0.70	28.514	28.695	0.63
30	55.333	55.948	1.11	26.400	26.400	1.10	26.962	27.25	1.07
60	45.831	55.629	1.45	27.332	27.332	1.60	26.614	26.99	1.44
90	26.226	26.6452	1.595	27.0853	27.0853	1.650	26.8433	27.254	1.530

Table 7

Volume change of particles immersed in the associated water

No.	1			2			3		
	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %	$V_{1,3}$, cm	$V_{2,3}$, cm	ΔV , %
10	50.0	50.0	0.0	50.0	50.0	0.0	50.0	50.0	0.0
30	50.0	50.5	1.0	50.0	50.5	1.0	50.0	50.5	1.0
60	50.0	51.0	2.0	50.0	51.0	2.0	50.0	51.0	2.0
90	50.0	51.52	2.5	50.0	51.1	2.2	50.0	51.1	2.2

Table 8

Weight change of granules immersed in distilled water

No.	1			2			3		
	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %	W_1 , gr	W_2 , gr	ΔW , %
10	56.003	56.003	0.000	26.761	26.762	0.00	26.723	26.723	0.00
30	54.40	54.40	0.000	27.058	27.058	0.12	26.599	26.599	0.00
60	55.48	55.489	0.000	26.303	26.303	0.00	26.084	26.084	0.00
90	55.37	55.37	0.000	26.8300	26.8300	0.000	27.1665	27.1665	0.000

Table 9

Volume change of granules immersed in distilled water

No.	1			2			3		
Immersion time, days	$V_{I,3}$ cm	$V_{2,3}$ cm	ΔV , %	$V_{I,3}$ cm	$V_{2,3}$ cm	ΔV , %	$V_{I,3}$ cm	$V_{2,3}$ cm	ΔV , %
10	50.0	50.0	0.0	50.0	50.0	0.0	50.0	50.0	0.0
30	50.0	50.1	0.2	50.0	50.1	0.2	50.0	50.1	0.2
60	50.0	50.0	0.0	50.0	50.0	0.0	50.0	50.0	0.0
90	50.0	50.0	0.0	50.0	50.0	0.0	50.0	50.0	0.0

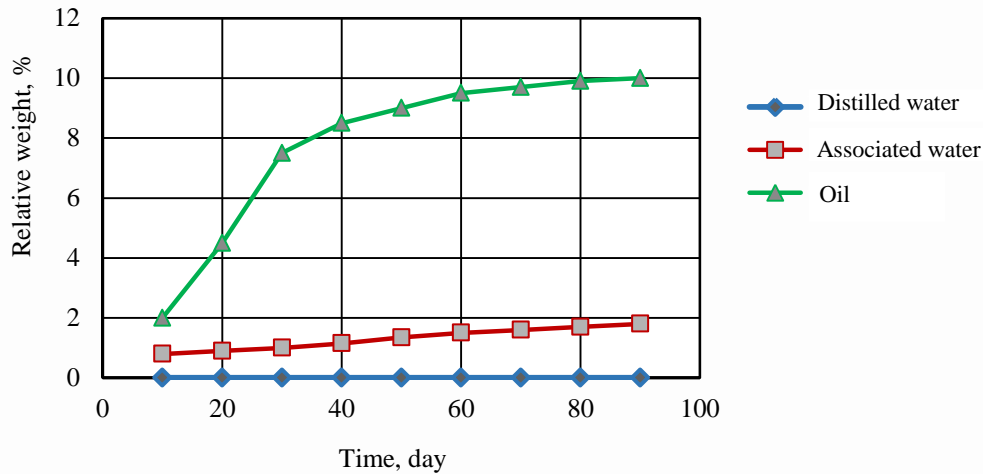


Fig. 3. Relative weight change of the immersed granules by time

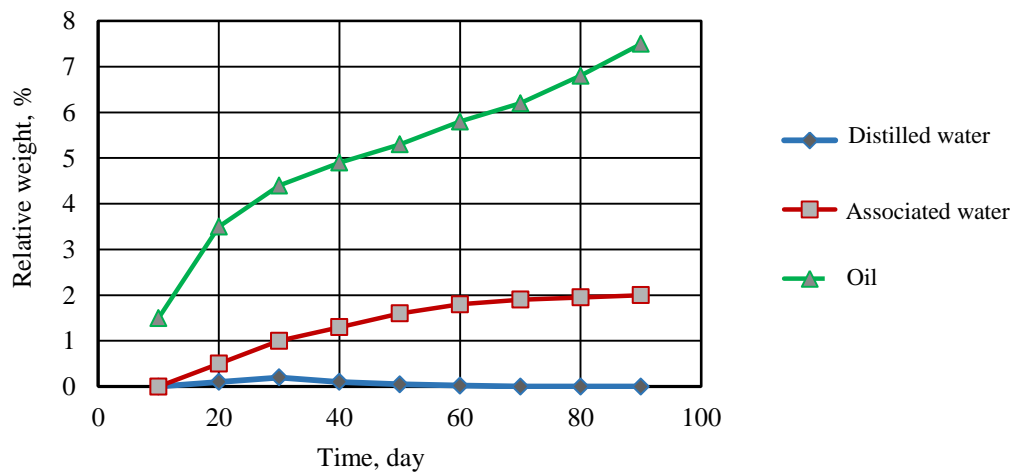


Fig. 4. Relative volume change of immersed granules by time

Figures 3 and 4 show that the time dependence of the relative weight and size changes of polyethylene granules has the character of a quadratic dependence and follows Fick's law in diffusion in the cases of three studied liquids (distilled water, associated water and oil), which indicates that the diffusion speed of liquid through polyethylene is the most important factor.

The relative weight change of granules immersed in the distilled water is not mentioned, but it is rarely noticeable in the associated water and increases more in the oil, as shown in Figure 4. This is due to the fact that salt diffusion significantly effects on the relative weight and volume between the granules immersed in the distilled water, on the one hand, and the granules immersed in the oil and related water, on the other hand.

The test results of the pipe weight and thickness changes, in which oil and associated water flow, are systematized in Tables 10 and 11. A graphical dependence of the pipe relative weight and thickness changes, through which the oil passes with the associated water flow shown in Figure 5 and 6, was obtained.

The sample cross section micrographs were taken before and after the tests with a 510-time increase and shown in Figure (7).

Table 10

Pipe weight and thickness changes through which oil flows

Immersion time, days			30		60		90	
Pipe number	W_l (gr)	X_l , mm	W , %	ΔX	ΔW , %	ΔX	W , %	ΔX
1	18.019	2.483	0.60	0.024	1.07	0.05	3.02	0.17
2	18.6440	2.485	0.90	0.032	1.12	0.07	3.01	0.19
3	18.6009	2.490	0.58	0.022	1.14	0.07	3.12	0.21
4	18.6441	2.483	0.91	0.032	1.12	0.096	3.00	0.19
5	18.5999	2.487	0.37	0.022	1.13	0.08	3.11	0.22

Table 11

Pipe weight and thickness changes through which the associated water flows

Immersion time, days			30		60		90	
Pipe number	W_l (gr)	X_l , mm	W , %	ΔX	W , %	ΔX	W , %	ΔX
1	15.22	2.483	0.399	0.012	0.521	0.025	1.35	0.087
2	19.134	2.484	0.404	0.015	0.478	0.029	1.42	0.086
3	15.905	2.483	0.409	0.011	0.459	0.028	1.38	0.075
4	18.6009	2.400	0.39	0.013	0.469	0.027	1.40	0.080
5	18.019	2.483	0.38	0.012	0.498	0.027	1.39	0.079

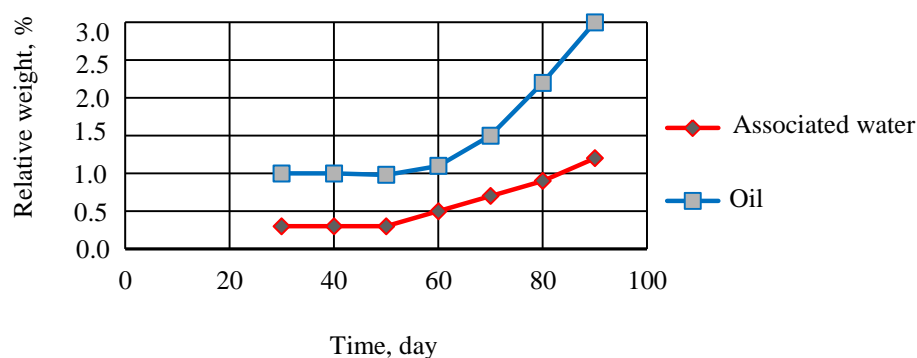


Fig. 5. Pipe relative weight change through which oil and associated water flow, over time

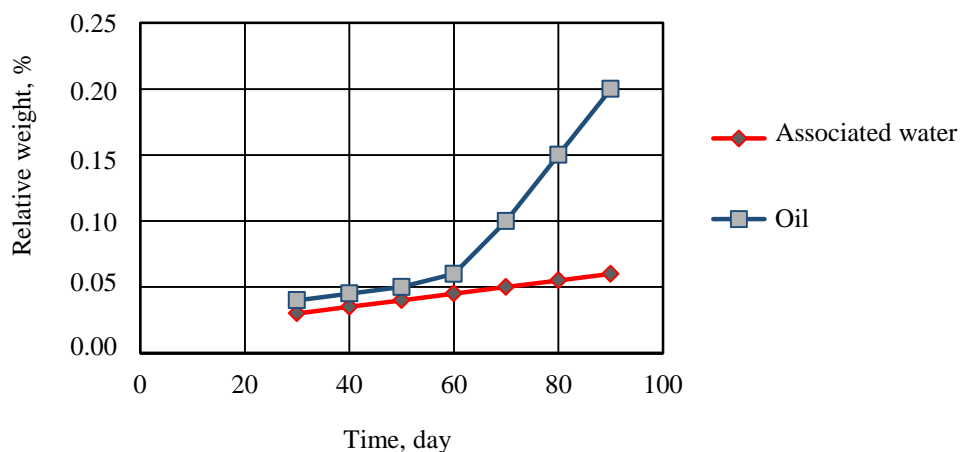


Fig. 6. Pipe relative thickness change in which oil and associated water flow, depending on time period

Due to Figures (6) and Table (12), it is noted that the relative change in the weight and thickness of the polyethylene pipe walls through which oil passes is greater than those through which the associated water passes, which indicates that polyethylene is more affected by oil.

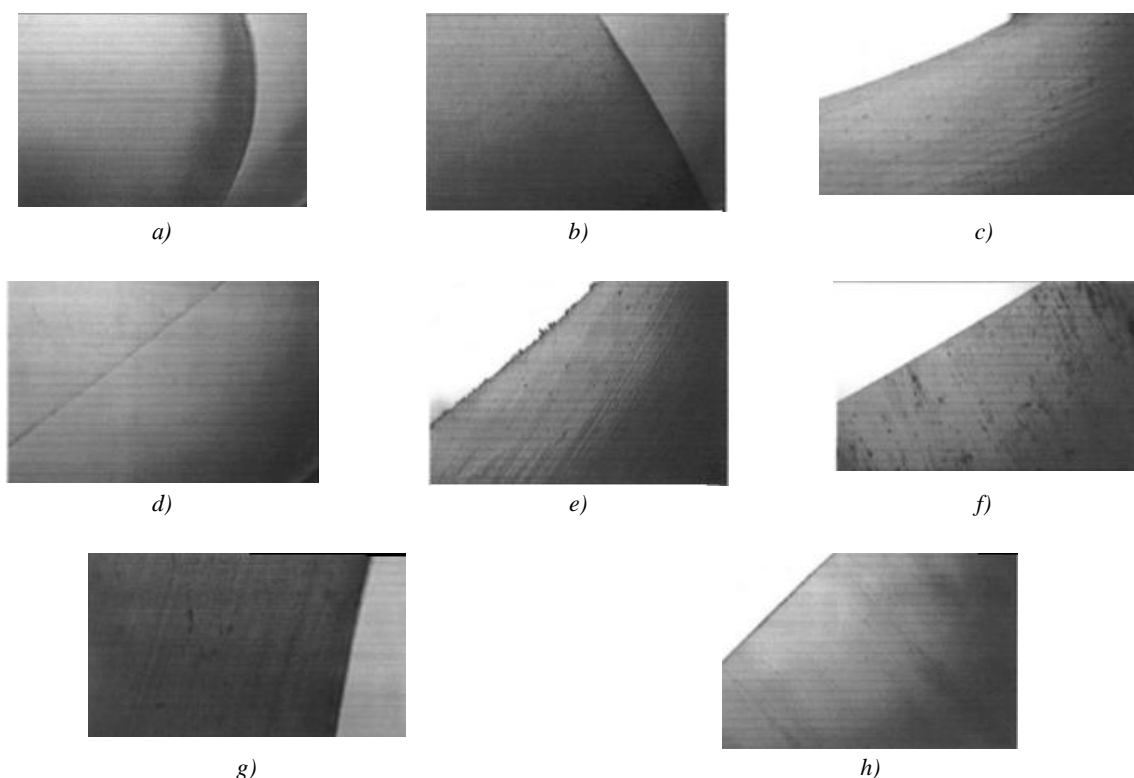


Fig. 7. Sample cross section micrographs before and after tests with a 510-time increase: *a* — cross section of a clean granule; *b* — cross section of an oil granule; *c* — cross section of a pipe with associated water in oil; *d* — cross section of a pipe immersed in oil; *e* — inner surface of the pipe with associated water; *g* — cross section of the pipe immersed in oil after 200 hours; *h* — inner surface of the pipe immersed in oil

Figure 7 shows cuts of pipe and granules samples before and after the tests, reflecting the surface colour and smoothness of the cross sections subjected to the tests, compared to the clean cross sections, which confirms the previous results obtained due to the basis of the graphs.

Conclusions

The experiments and the results obtained have shown that the liquid diffusion speed through polyethylene is the most significant factor. Immersion in oil has a greater impact than immersion in associated water and distilled water according to the presence of salts.

It has been found out that the relative change in the weight and thickness of the polyethylene pipe walls through which oil passes is greater than those through which the associated water passes, and the microscopic cross sections images in the samples before and after the tests have confirmed the obtained results.

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